Center for Independent Experts (CIE) Individual Peer Review Report on a Review of Sea Scallop Survey Methodologies and their Integration for Stock Assessment and Fishery Management (17–19 March 2015, New Bedford, Massachusetts, USA)

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1. Executive Summary

The reports, papers, and presentations prepared by the various research teams for this review amply demonstrate the knowledge, skill, and creativity of those teams and it is in no small way that the recent success of this fishery has depended on their combined efforts. The panel found no serious flaws in any of the work presented.

All the surveys were well-designed to achieve their objectives, although the objectives varied among the surveys and were not always well-specified. There are potentially some issues with the systematic designs of the Virginia Institute of Marine Science (VIMS) and School for Marine Science and Technology (SMAST) surveys for estimating biomass and its variance, but other objectives may justify the use of systematic surveys. Physical samples taken using dredges are inherently superior to image-based methods for estimating length composition, the proportion of live scallops, and physiological attributes (e.g., grey meats). There are potential issues with scallop detectability (especially with respect to length) for both dredge and optical surveys; these seem most obvious for the SMAST drop camera surveys but historical estimates can be corrected using existing data. Optical surveys are inherently superior to dredge surveys for detecting recruitment of juveniles and providing insights on fine-scale ecology but these capabilities can be improved and expanded. The HabCam4 system is particularly promising in this regard and automated image processing and analysis offers substantial increases in sampling power for the future.

The design-based methods of estimating abundance used in most of these surveys are straightforward and well-understood. Minor improvements can be made, especially to variance estimation, but none of the indices is likely to be unreliable. The model-based methods currently used for HabCam surveys work well in areas with reasonable transect spacing, but still need some development in more sparsely-sampled areas (noting that this is primarily a data sparseness problem rather than a methodological problem). Current methods of combining survey data or estimates all have problems of one sort or another and further development seems required. All survey systems can provide useful information for purposes other than sea scallop monitoring, and some such time series are already in routine use. The HabCam4 system is particularly promising because of its ability to generate very large amounts of data across continuously-variable spatial scales. Some potential avoidance issues for mobile species may need to be addressed.

It is not possible to estimate or specify the optimal frequency or combination of survey and sampling methods until the full suite of objectives is known. However, once the objectives are known and understood, it will be possible to assess fruitful and cost-effective ways forward using simulation modelling. Several clear ways to improve information and understanding came up during the review, but I believe the biggest advances will be gained by specifying and ranking the full suite of objectives for the information. Once this is done, it becomes much easier to design a research programme, conduct simulation modelling, and chart a way forward.

2. Background

The Atlantic sea scallop, *Placopecten magellanicus*, is a bivalve mollusc occurring on the eastern North American continental shelf from Cape Hatteras to the Gulf of St. Lawrence and Newfoundland. Major aggregations occur in the Mid-Atlantic from Virginia to Long Island, on Georges Bank, in the Great South Channel, and, to a lesser extent, in the Gulf of Maine (Hart and Chute 2004). The fishery for Atlantic sea scallop is one of the most valuable in the USA and the most productive wild scallop fishery in the world. In large part, this appears to be due to the collaborative work of fishers, scientists, fishery managers, and environmentalists. Biomass and catch rates generally declined from the 1960s through the mid-1990s as fishing mortality increased (Hart & Rago 2006). In 1994, managers closed three large areas on Georges Bank to any gear that could be used to target groundfish or scallops to allow both groundfish and scallop populations to recover. They also altered other fisheries regulations, gradually increasing the minimum dredge ring size from 3 inches to 4 inches, allowing small scallops to escape and grow to larger sizes before being caught. They put limits on crew size and days that each vessel could fish to reduce fishing pressure on scallops. Managers implemented spatial rotation for the scallop fishery — they defined management areas around concentrations of sea scallops on Georges Bank and off the Mid-Atlantic states that are closed to enable young scallops to grow undisturbed and reproduce, and then reopened when ready to harvest. Between 1994 and 2005, the biomass on Georges Bank increased almost 20-fold and that in the Middle Atlantic Bight increased about 8-fold. Flexible and precautionary fisheries management informed by multiple surveys and comprehensive analysis appears to have been successful in maintaining high and stable landings averaging about 25,000 t (meatweight) between 2003 and 2012. This is almost three times higher than the average over the second half of the 20th century; it is a remarkable success story.

The value of the fishery has prompted and supported significant research and surveying funded by federal agencies and, since 2000, through a research set-aside programme (RSA) administered by the Northeast Cooperative Research Partners Program (NCRPP) established by the Northeast Regional Office and the Northeast Fisheries Science Center (NEFSC) of NOAA–Fisheries in 1999. RSA programmes promote partnership among fisheries participants, scientists, and fishery managers to further the understanding of northwest Atlantic fisheries and enhance information used in fisheries management decision-making (Feeney et al. 2010). Special committees of the regional federal fishery management councils set the research priorities and researchers compete for funding. NOAA-Fisheries manages the competition, award, and reporting process but does not retain or use any of the funds (see http://www.nefsc.noaa.gov/coopresearch/news/scallop-rsa-2014-awards.html for awards made in 2014).

The variety of funding mechanisms and perspectives on the fishery led to a variety of different scientific studies and research surveys, the most recent of which uses sophisticated towed "HabCam" systems. On 20 April 2012, the New England Fishery Management Council voted to task its Science and Statistical Committee (SSC) to:

1) review the sea scallop HabCam survey technology and methods to determine if the HabCam is appropriate at this time for performing annual sea scallop surveys, and

2) review how HabCam results will be integrated into sea scallop assessments for determining biomass and fishing mortality, and determine the impacts of reduced survey coverage from current dredge and SMAST video surveys.

Further discussions broadened the scope of this task to examine all of the primary survey methods for assessing sea scallop abundance. These include dredge surveys conducted on research vessels, dredge surveys conducted on commercial vessels, drop camera surveys implemented by SMAST, and the HabCam system developed by the Woods Hole Oceanographic Institute (WHOI) and NEFSC. The objectives of this broader scope were to assess the strong and weak points of each sampling approach, and identify the complementary facets of each survey methodology and opportunities for each method as part of the scallop survey sampling program going forward. This Review of Sea Scallop Survey Methodologies and their Integration for Stock Assessment and Fishery Management is an integral part of that wider task.

A panel of four expert reviewers with an independent chair was established[1] and, to guide their review, provided with the following Terms of Reference:

1) Review the statistical design and data collection procedures for each survey system
   a. Dredge surveys conducted on research vessels
   b. Dredge surveys conducted on commercial vessels
   c. SMAST video drop camera system
   d. HabCam camera and sensor sled

2) For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (e.g., light, turbidity, sea state, tide etc.)

3) Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (e.g., Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

4) Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

5) Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

6) Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

7) Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

8) Identify future research and areas of collaboration among investigators and institutions

[1] Panel members were Noel Cadigan, Martin Cryer, Jon Helge Vølstad, and Brent Wise, chaired by Jean-Jacques (J-J) Maguire

The panel met at the Waypoint Event Center at the Marriott Fairfield Inn and Suites, New Bedford, Massachusetts, USA, between 17 and 19 March 2015. The panel reviewed material prepared and provided by four independent scientific teams conducting sea scallop surveys and/or research: the North East Fisheries Science Center of NOAA-Fisheries (NEFSC), the Virginia Institute of Marine Science, College of William and Mary (VIMS); the University of Massachusetts Dartmouth, School for Marine Science and Technology (SMAST); and Arnie's Fisheries.

3. Role in the Review

The review panel comprised four scientists appointed by the Center for Independent Experts (CIE) as having expertise in one or more of the following fields:

1) Use of optical imaging in estimating abundance in marine biological surveys,
2) Statistical design and estimation of surveys for stock assessments including stratified random, systematic and transect surveys,
3) Model-based estimation of abundance using geostatistical tools, or
4) The use of dredge surveys for sessile benthic organisms,
5) Knowledge of sessile invertebrates and spatial management (desirable).

I have experience, expertise, and publications in the use of optical imaging for estimating abundance (mostly for New Zealand scampi, *Metanephrops challengeri*, depths 200–600 m), the use of dredge surveys for quantitative estimates of abundance (for New Zealand scallops, *Pecten novaezelandiae*, depths 10–65 m), and in the statistical design of surveys for a range of sessile and mobile species using various stratified random and systematic surveys and/or transects (intertidal to deep ocean). I have been involved in the scientific and management aspects of invertebrate fisheries since 1977. My direct knowledge of model-based estimators of abundance is limited.

The review panel was assisted by the NEFSC Stock Assessment Workshop (SAW) Chairman, James Weinberg, Paul Rago, Acting Chief of the NEFSC Resource Evaluation and Assessment Division and Deirdre Boelke from the New England Fisheries Management Council. Presentations were made by Paul Rago, Dvora Hart, Dave Rudders, Kevin Stokesbury, Scott Gallager, Richard Taylor, Burton Shank, Jui-Han Chang and Deirdre Boelke. Toni Chute and Larry Jacobson from the NEFSC acted as rapporteurs. Aside from the panel, 49 people attended the sea scallop survey methodologies review meeting in one capacity or another.

My role in the review consisted of reading most of the many review and background documents provided in advance of the review meeting, attending and participating in the review meeting from 17-19 March, 2015, discussing and agreeing on the content of a panel report coordinated by the Chair, and providing this independent peer review report. During the review meeting, I concentrated on those areas where I have the most knowledge, the use of optical and dredge surveys to estimate abundance and stock status. When model-based estimation was discussed, I asked mainly questions of clarification during the technical presentations but had more involvement in discussions about the presentation of results, especially around the communication of uncertainty. I have long experience in communicating complex science results to fisheries managers, fishers, and other fisheries stakeholders.

4. Key Findings by Term of Reference

Each survey approach has strengths and weaknesses and it is somewhat difficult to draw firm conclusions on the weight that should be put on these strengths and weaknesses unless the full suite of objectives for the work is known. It was clear at the review meeting that one or more time series of relative (or absolute) biomass was required as an input to a stock assessment model to determine stock status, but also that information on spatial distribution, growth, mortality, and meat condition were required to underpin various spatial and other management processes. However, I don't believe that the full suite of objectives was presented to the panel, and it may be that this does not exist in a single document. I will return to this theme later in my review but having such a document should, I believe, be the first step in reviewing the value of research studies and surveys and designing an optimal package of surveys to meet future information needs.

4.1. ToR 1: Statistical design and data collection

The ToR was to review the statistical design and data collection procedures for each survey system:

a. Dredge surveys conducted on research vessels
b. Dredge surveys conducted on commercial vessels
c. SMAST video drop camera system
d. HabCam camera and sensor sled

The panel report concludes that this ToR was addressed satisfactorily by all presentations and, although I have several recommendations, I agree with that conclusion.

Federal dredge surveys using research vessels provide a long time series of biomass estimates for use in stock assessment modelling. Such surveys have been conducted since 1960, covered a more consistent area since 1975, and have used a stratified random statistical sampling design since 1977, albeit with reduced coverage in recent years. The survey has been conducted using different vessels, mostly on NOAA R/V Albatross IV and Hugh Sharp, but this was not seen by the panel as a weakness because comparative fishing experiments using various vessels have repeatedly shown no vessel effect. This very much surprised me because my experience of New Zealand scallop fisheries using toothed "box dredges" suggests strong vessel effects related (not always in obvious ways!) to the several adjustments possible on a box dredge and the skill and attention of the skipper. I read the papers provided and did some more background reading and I am reasonably confident in the researchers' conclusion that no strong vessel effect exists, but it would perhaps be useful if some assessment of the statistical power of the studies could be made. It may be that, because the survey and New Bedford dredges do not have teeth and do not rely on hydrodynamic depressor plates like the New Zealand box dredges, they cannot be "tuned" to the same extent, and thus the towing characteristics of the vessel (vessel size, horsepower, reduction gear, and propeller) have little effect on the way the gear works on the seabed.

The dredge surveys on research surveys are well-designed (stratified random, focussing mostly on generating reliable estimates of abundance) and apply appropriate and rigorously-standardised sampling protocols. These surveys are currently the best suited of all the survey methods to providing the long time series of abundance indices necessary for successful stock assessment modelling and it is important for the stock assessment that a survey with as comprehensive a coverage as possible is continued. Other survey approaches either do not have a long time series or do not have the full coverage required. The disadvantage of these surveys is that, because they are optimised for stock-wide biomass estimates, they cannot (at the current sampling intensity) provide detailed and reliable information on distribution or abundance within (relatively) small geographical areas.

The coverage of the federal dredge survey has reduced somewhat over time, it seems largely to reduce costs and/or free-up resources for HabCam surveys. Reducing coverage entails some risk that the survey biomass estimates may become less reliable (less precision and potential bias). I and the rest of the review panel think that surveys with greater spatial coverage tend to be less prone to bias and provide more accurate estimates of stock size, especially for populations like sea scallops whose spatial distribution can vary substantially from year to year or on longer time horizons. One way to increase the coverage (and survey precision) that came up at the review meeting would be to decrease the tow length at each station. The panel was told that information exists that could be used to assess the costs and benefits of reducing tow length, and additional comparative tows could be conducted if the existing information is insufficient. Discussion at the meeting suggests an additional one or two stations each sea day might be possible if tows were made shorter.

The VIMS dredge surveys uses commercial vessels and are cooperative with industry. These surveys are quite well-suited to the generation of detailed information on the distribution abundance of scallops in areas closed to fishing to evaluate when these could be re-opened and how much could be harvested in individual areas. They apply almost identical sampling protocols to the federal surveys and also rely on the (apparently reasonable) assumption that there is no vessel effect. They have provided some interesting comparisons of research and commercial dredges. The VIMS surveys use a systematic sampling grid with a random start point and they do not cover the entire stock. Thus, they have disadvantages compared with the federal surveys that they cannot be used to generate stock-wide biomass estimates, they are statistically inefficient for estimating biomass in the areas applied, and there are problems estimating the variance for biomass estimates. It has been proposed that the design for this survey be changed to stratified random, but I believe this decision should not be taken lightly; there are benefits associated with both types of design and the existing federal and VIMS data should be analysed to assess the trade-offs before a decision is made. The review panel notes, and I agree, that these surveys pursue multiple objectives, and these additional considerations may warrant a systematic sampling design.

The SMAST video drop camera system was originally developed to estimate biomass in closed areas, but the scope and coverage has expanded progressively. This is a cooperative survey with the fishing industry and has the advantages of being easily understood and easily implemented at sea by non-specialists. The systematic sampling design can be used to estimate biomass over large areas with only trivial risk of bias due to sampling "in phase" with the natural variation or patchiness of scallops (the one circumstance where systematic surveys can produce badly biased results), but care should be taken not to "over-interpret" distribution and biomass results at finer scales. This is because, in contrast with the VIMS dredge surveys which use the same design approach, the SMAST survey covers only a very small sampling area at each station (a few square metres integrated over a few tens of metres compared with several thousand square metres integrated over several hundreds of metres). Analyses from HabCam continuous visual transects suggest that it is not uncommon for spatial variation in scallop density to occur at scales of a few kilometres, comparable with the grid size of both the VIMS and SMAST systematic surveys. Thus, there is some risk that the small sampled area and the systematic design could combine to generate quite misleading estimates of density at the scale of a few kilometres in the SMAST surveys. The larger the scale over which conclusions are drawn, the lower the risk and, over the whole survey area, the risk is probably vanishingly small. Some simulations using information from the HabCam continuous visual transects could be used to assess these risks.

There are two HabCam surveys, one using HabCam V4 conducted on the NOAA research vessel Hugh Sharp and one with HabCam V2 conducted by Arnie's fisheries. The HabCam2 survey has generally followed a systematic transect sampling design with high intensity sampling along orthogonally arranged transects in particular areas of interest. HabCam4 surveys are still developing and, thus far, have not completely covered the stock area. Work is continuing on finalizing a statistical sampling design that would be set before the beginning of a survey with the HabCam4. Both HabCam surveys, but particularly the HabCam4 surveys, provide very detailed information along transects that can be analysed at a continuously-variable range of spatial scales from centimetres to tens of kilometres. This information can be used to inform geostatistical model-based estimates of density and biomass (together with model-conditioned estimates of variance) and address a variety of other questions. However, the typical distance between transects, especially for HabCam4 surveys, seems wide for making precise biomass estimates. I believe this is because the method is still under some development and the implementation competes for resources with the dredge survey.

Conclusions and recommendations for ToR 1

All the surveys were well-designed to achieve their objectives, although the objectives varied among the surveys. There are potentially some issues with the systematic designs of the VIMS and SMAST surveys for estimating biomass and its variance, but these other objectives may warrant the use of systematic surveys. I have the following recommendations for this ToR:

- Continue comprehensive stratified random dredge surveys to generate the time series of abundance indices for the stock assessment model
- Assess the potential for shorter tows in the dredge surveys to deliver more stations and improved precision for the same cost
- Assess the benefits and trade-offs associated with systematic and stratified random designs for the VIMS dredge survey before changing the design
- Assess the risk of bias in density estimates on the scale of kilometres caused by the small sampled area and systematic design of SMAST surveys
- Continue the development of efficient and practical designs for HabCam surveys

4.2. ToR 2: Measurement error and confounding factors

The ToR was, for each survey, to evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (e.g., light, turbidity, sea state, tide, etc.)

The panel concluded all presentations addressed this term of reference satisfactorily and, although I have several recommendations, I agree with that conclusion.

The review panel concluded that the dredge surveys provide more accurate measurements of shell height than the optical surveys (both dropped and towed cameras) and reliable estimates of length compositions are very important for the length-based assessment model. There is some measurement error of scallops retained in a dredge and measured on deck but this appears to have been estimated appropriately and is encouragingly small. The review panel concluded that, whereas optical surveys provide almost complete detection of exploitable-sized scallops and better detection of very small recruits, dredge surveys had an efficiency of only 40% on sand and 24% on gravel. These are average values and are likely to vary depending on environmental, physical and substrate conditions (e.g. currents, slope, roughness of the bottom, other bottom types, etc.). These values are broadly similar to estimates for two different types of New Zealand dredges in a variety of substrates (e.g., Cryer & Parkinson 2006, Bian et al. 2012) and seem reasonable. To some extent, the integrating effect of towing scallop dredges will compensate for seabed variability on some spatial scales, but broader-scale confounding factors are more difficult to deal with. The effect of sea state / wave height has been explored and the conclusion that weather does not greatly affect catches seems reliable.

Dredges also inevitably have selectivity ogives for scallops and it is clear from the work presented at the review and in the background documents that these differ for research and commercial dredges. There appears to be a working assumption that the selectivity of research dredges for scallops of >40 mm is flat (meaning that length frequency distributions of scallops 40 mm length or greater are unbiased), but there is an indication, most obvious in the paper by Yochum & DuPaul (2008), that selectivity may, in fact, be somewhat domed. Yochum & DuPaul (*op.cit*.) estimated the selectivity of commercial dredges compared with research dredges that were assumed to be non-selective for the range of size classes considered. Their Figure 2 (p. 269) shows consistent negative residuals for very large scallops in the commercial dredge across several cruises using paired tows. Commercial fishing can introduce selectivity patterns through skipper choices, but the paired design of this experiment means that there must be some functional mechanism whereby very large scallops are caught less frequently in the large commercial dredge. This is counter-intuitive and it might be expected that the wider, heavier commercial dredge would be more efficient for large scallops than the research dredge or, at least, have monotonically increasing relative efficiency with increasing scallop size. If such a pattern occurs in commercial dredges, it is not unreasonable to assume that the same or other patterns might occur in research dredge selectivity and I think it would be worth exploring dredge efficiency and selectivity more thoroughly (especially if the resultant biomass estimates are to be used in stock assessment models as indices of absolute abundance or biomass). An alternative might be to estimate catchability (q) and selectivity parameters within the model using experimental information to develop priors (e.g., Tuck & Dunn 2012, Punt et al. 2013). If there is a domed selectivity pattern, the large increase in the proportion of very large scallops in recent years would mean that the dredge-based indices of biomass would have underestimated the real increase in biomass.

Aside from providing the best estimate of population length frequency (above about 40 mm shell length) the collection of physical samples of live (and dead) scallops with dredges also provides for a variety of other analyses of:

- the spatio-temporal variation in shell height to meat weight relationship, critical to the stock assessment;
- the proportion of recently-dead scallops (as an index of recent mortality);
- the prevalence of grey meats;
- gonad size and maturity;
- other measurements that require physical or laboratory examination of specimens.

The SMAST drop camera edge-effect correction method inflates the sampled area by including a buffer around the actual quadrat of width equal to half the average length of the observed scallops. This approach will overestimate the sampled area for small scallops because small scallops on the outer part of the buffer zone will not be visible in the quadrat. Conversely, very large scallops that are partly visible in the quadrat may extend beyond the buffer zone and thus the effective sampled area will be underestimated. Thus, only the density of scallops close to the mean size will be estimated without bias and there will be systematic trend from underestimation of the density of small scallops to overestimation of the density of large scallops. If density of individuals was the measure of interest, this might not matter much (although length frequency distributions would be distorted), but this bias becomes particularly important for exploitable biomass estimation because meatweight scales with a power of 3 (or, based on my experience with New Zealand scallops, ~3.2 or more) on length. It is better to correct for edge effects for individual scallops and there are methods of doing this that could be applied to existing data. A method I suggested at the meeting was to assess, for each observed scallop, whether its hinge or umbo was within the quadrat. The umbo is a distinctive feature of a scallop so it should be readily detectable in photographs. The fact that the umbo is very small relative to the size of the quadrats means that the necessary correction for edge effects becomes very small, and probably ignorable. Alternative methods include those applied to HabCam imagery where scallops more than half-visible in the image are included and those less than half-visible are excluded (those “exactly” half visible are included if they lie on either of two predetermined image edges and excluded if they lie on either of the other two edges). Any of these analytical approaches could be applied to the existing images and data to correct for the probable edge effect bias.

Judging by some of the images shown at the meeting, there appears to be some differential detectability of scallops near the borders and, especially, the corners of the SMAST photographs. This could arise from lighting effects and/or image quality effects (which would be consistent across all images) or from occlusions caused by disturbed sediment (which would be particular to some images, potentially differing with sediment type and state of the tide / currents). If either is true, and it is assumed not to occur, this will lead to some negative bias in density estimates. At the meeting, I suggested a method of assessing and correcting for the former type of such bias that could be applied to existing data. The counting and annotation system used by SMAST holds the X and Y coordinates within the quadrat of each scallop counted, plus the estimated length of each scallop.

This is a powerful data source for estimating relative detectability within quadrats. Over a large number of quadrats it is possible to plot the distribution and density of detected scallops within an average quadrat. Scallops are known to be patchy at a variety of spatial scales but, over a large number of quadrats, there is no reason to suppose the average distribution within a small quadrat should not be random. The distribution of observed scallops can be compared with the expected distribution and, based on the images I observed, I would expect to see the ratio of observed to expected density of scallops per unit area to decrease towards the edges and corners in a relatively predictable way. The estimated detectability pattern could be used to correct for the probable negative detectability bias.

The very large amount of data available would also permit SMAST or another researcher to assess whether the detectability bias varied with factors like scallop size, depth, sediment type, state of the tide, currents, or the presence of other fauna. If lighting position, type, or wattage, or camera position has changed at any time, an assessment can be made of the consequences of those changes for relative detectability of scallops within the quadrats using this method. It should be clear that this method cannot be used to assess absolute detectability or efficiency; it can only be used to assess patterns within the quadrats (the implicit assumption usually being that there is some place within the quadrat where 100% of scallops are detected).

HabCam surveys, both V2 and V4, are analysed using highly sophisticated image processing procedures, including flattening the light-field and correcting for the preferential absorption by seawater of colours with longer wavelengths. These are likely to remove much of the variable detectability issues that might occur (as in the SMAST drop camera surveys), and may have some benefits for measurement accuracy as well. I and the rest of the panel encourage further development of these approaches. It is clear that all the optical approaches introduce measurement error over and above that associated with callipers or either manual or electronic measuring boards. To an extent, this is probably unavoidable, but the HabCam team have done a good job of assessing the current variance, and appear to have corrected the gross errors and bias associated with scallops that are tilted or swimming off the seabed (using the stereo imagery in HabCam4). Their correction for edge effects is appropriate and unbiased (see above).

Conclusions and recommendations for ToR 2

Physical samples taken using dredges are inherently superior to image-based methods for estimating length composition, the proportion of live scallops, and physiological attributes (e.g., grey meats). There are potential issues with scallop detectability (especially with respect to length) for both dredge and optical surveys; these seem most obvious for the SMAST drop camera surveys but historical estimates can be corrected using existing data. Automated image processing and analysis offers substantial increases in sampling power for the future. I have the following recommendations for this ToR:

- Explore methods of estimating dredge efficiency, especially whether there may be domed selectivity of research dredges (if using optical length frequencies in a comparison, some means of filtering out the additional measurement error or otherwise deconvoluting the optical length frequencies would be required)
- Assess and, if warranted, correct for edge effect bias in the SMAST survey results

- Assess and, if warranted, correct for differential detectability of scallops within SMAST quadrats
- Consider applying image processing to flatten the light field and correct for attenuation in the SMAST images
- Continue the development of image processing and analysis algorithms

4.3. ToR 3: Biological sampling and fine-scale ecology

The ToR was to review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (e.g., Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

The panel concluded that all presentations addressed this term of reference satisfactorily and I agree with that conclusion.

It seems clear to me that, although the dredge surveys provide the best length frequency distributions for stock assessment or cohort growth modelling purposes, the optical methods provide better ability to detect incoming recruitment of very young scallops and have the potential to provide near-absolute estimates of density and abundance. The additional measurement error causes some problems for interpretation, especially in the HabCam2 and SMAST surveys where stereo imagery is not used, and very small scallops are not easily distinguished from some seabed features, so the ability to foretell recruitment is probably best considered semi-quantitative (at best). Although the optical surveys have higher detectability of scallops < 20 mm than the dredge surveys, and therefore provide better information on recruitment, they provide less accurate information on larger scallops (i.e. 40mm+) because the optical sampling and analytical procedures introduce statistical noise. This leads to distributions of size (shell heights) being widened (very small and very large scallops can be "invented" by the optical systems) and cohorts being "smeared" together (an excellent example was shown during the review where a clearly-trimodal length frequency distribution appeared unimodal using an optical system). However, there is some potential for dredges to have a dome-shaped selection pattern (see ToR 2) which would lead to negative bias in the proportion of very large scallops in dredge length frequency distributions.

Because they explicitly show close associations between individuals (of the same or different species) and can be analysed at more than one scale, both towed and dropped cameras potentially provide better information on predator-prey interactions than dredges (which integrate over hundreds of metres). I agree with the rest of the review panel that finfish avoidance is potentially more of a problem for the towed camera than for the drop camera. However, there are tremendous benefits of having the very large number of images and the continuous visual transects and ability to assess at a continuously-variable range of spatial scales that towed HabCam provides, and I believe that avoidance can be tested and potentially corrected. One approach might be to include forward-looking low-light video cameras toward the front of the frame, giving an indication of the species that were avoiding, at what position relative to the approaching towed camera they initiated a response, in what direction they moved, and whether they were eventually detectable by HabCam's downward-looking cameras.

The review panel appreciated the complexity and magnitude of work involved in processing the large amount of data collected using all of the optical systems, but especially with the HabCam V4 system. Having led many surveys using optical approaches myself, and participated in and analysed the post-voyage screening and counting, I was very impressed with the progress that has been made in this area and I am enthused about future possibilities based on what I saw during the review. I endorse the review panel's recommendation for further development of automatic image processing capabilities because this will allow substantially more information to be derived from the same amount of sampling effort and analytical resources, and will provide new insights. I also endorse the review panel's conclusion that only HabCam4 equipped with side scan sonar can be used to detect scours and linear features associated with the impacts of fishing gear. Having such knowledge is not the only approach to assessing the impacts of fishing, however, and I favour broad scale assessments (see Cryer et al. 2002) as well as the highly focussed analyses that close linking offside-scan and images will allow.

Understanding of meatweight and its variation in time and space is important for the management of the fishery. Subsampling for meat weights during dredge surveys seems minimal and to be currently done in a rather *ad hoc* manner during NEFSC dredge surveys. I agree with the rest of the panel that, given the importance of this information and the fact that it can never be gathered using optical methods, a more formal statistical sampling design should be developed and applied. Similarly, more information on the total number of baskets and fraction sampled and the between-basket variation in scallop counts could be recorded and provide useful information on this source of variation. The SMAST and HabCam imagery both represent large and rich databases for assessing fine-scale ecology and I can imagine both keeping many students and researchers fruitfully busy for many years; I have to admit I greatly envy this resource!

Conclusions and recommendations for ToR 3

Optical surveys are inherently superior to dredge surveys for detecting recruitment and providing insights on fine-scale ecology but these capabilities can be improved and expanded. The HabCam4 system is particularly promising in this regard. I have the following recommendations for this ToR:

- Explore ways of assessing and correcting for avoidance of both image-based and dredge sampling methods
- Continue the development of the image processing and automated screening and counting of images through the HabCam system
- Explore approaches to reducing bias and increasing precision of size measurements made using optical systems
- Develop a formal sampling design for meatweight and any other biological measurements of scallops (and, as applicable, other species)

4.4. ToR 4: Abundance indices

The ToR was to review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

The panel concluded all presentations addressed this term of reference satisfactorily and, although I have several recommendations, I agree with that conclusion.

The federal NEFSC dredge surveys have, for many years, been conducted using a stratified random design for which estimators of mean and total abundance and their variances are straightforward and well-understood. However, the coverage of the surveys has declined over the years and this will lead to negative bias in estimates of stock-wide biomass if there are any scallops in the un-surveyed areas. If there are few scallops in the un-surveyed areas, or they are widely distributed at very low density, then the coverage bias may be a trivially low and a worthwhile trade-off for the additional precision afforded by the more focussed survey. Also, if scallops outside the survey area are at very low density the surveyed area may cover all the commercially catchable scallops and/or all the scallops that can effectively participate in spawning. Several times during the review, however, it was noted that large numbers of scallops could be found, sometimes at high densities, in areas where they had previously been uncommon. This is typical of many scallop species, and is a feature of their biology that can lead to underestimates of stock biomass estimates from surveys that are aggressively optimised for precision (e.g., by leaving out areas thought to have few scallops). This is a difficult trade-off, but I suggest keeping the coverage of the federal dredge surveys relatively broad and/or maintaining some other “watching brief” on peripheral areas to mitigate the risk.

Dredge efficiency of the federal surveys has been estimated relative to optical surveys but, because of the length-estimation problems for the latter, the fact that efficiency for optical surveys had to be assumed to be 100%, and because there may be non-linear or domed selectivity in the dredges, I suggest the current assumed scalars of 40% and 24%, linear across all size classes, be revisited as time and resources allow. This might include reconsideration of variance associated with the correction and/or separate estimation of q or selectivity ogives within the stock assessment model. Because the length frequency of scallops in the stock has clearly and dramatically changed over time, even modest changes to selectivity (efficiency at length) could cause some bias in the biomass indices for some years relative to others. In addition, if dredge efficiency varies geographically or with depth and scallops are distributed differently from the range of substrates and depths examined, there is some scope for bias in overall estimates of biomass. I suspect these will be small if dredge efficiency was estimated in broadly representative parts of the fishery / stock. If comparison with optical counts is used for the assessment of dredge efficiency (and other methods like depletion experiments and mark-recapture experiments are available), then some method of deconvoluting or filtering the image-based length frequency distributions needs to be found to correct for the bigger length measurement errors in data from images. If this is not done, there is a risk that dredge selectivity curves will appear more domed than they really are, and this can introduce a systematic and very undesirable positive bias in biomass estimates (through the invention of a “cryptic biomass” of very large scallops).

The VIMS dredge survey is post-stratified into sub-areas and the standard design-based methods are used to estimate abundance and biomass within sub-areas and to aggregate estimates for all areas. The survey uses both a commercial and a survey dredge, and the efficiency of both gears has been previously estimated and corrections applied to estimate abundance and biomass. Potential biases in the efficiency estimates in time or space will affect the accuracy of the survey biomass estimated. I and the rest of the review panel agree with the VIMS scientist that the variance estimation has issues related to 1) the systematic sampling design, 2) unaccounted measurement error, 3) efficiency corrections. The VIMS scientist indicated the survey design may be changed to attempt to address some of these issues, but I think (see ToR1) that this decision should not be taken lightly and should depend on the objectives of the survey.

The abundance and biomass estimation methodology, and variance estimators, for the SMAST drop-camera survey seemed appropriate, subject to the probable positive bias in biomass associated with the method of correcting for edge effects and the probable negative bias in density, especially for small scallops, associated with detectability of <100% towards the edges and corners of each photograph, and the variation of these biases over time and with factors like depth, substrate, or currents. This survey, like the VIMS dredge survey, uses a statistical uniform systematic design, and estimates of variance for biomass estimates also have bias (almost certainly positive) related to 1) the systematic sampling design, 2) unaccounted measurement error, 3) uncertainty due to edge corrections. Perhaps in contrast with the rest of the panel, I believe there is some potential for density and biomass estimates to be misleading over small to moderate scales (see ToR1) but probably not over large scales. The uniform allocation of stations may well be reasonable and more appropriate for multiple objectives, including assessment of spatial pattern and the detection of new recruitment of scallops, but will be inefficient for the estimation of abundance of exploitable biomass because substantial sampling effort will be allocated to areas with low abundance of larger scallops.

For both HabCam surveys, three model-based methods (ordinary kriging, GAM/GAMM with kriging) and a design-based method (stratified mean) were tested through simulations. A model based approach involving a hurdle-GAM for large scale trend plus kriging on residuals was used for several (~14) large areas. This was a complicated model that the review panel did not fully investigate and is outside my areas of expertise, but it was selected by the analyst as the best method giving low bias in the simulation studies and the lowest root mean square error. However the review panel noted that there was no single method that performed best across all simulations. The review panel concluded that the geostatistical modelling approach seems reasonable but that biomass variance estimates are likely under-estimated because degrees of freedom were not adjusted for and model uncertainty is an unaccounted source of variation in the biomass and abundance estimates. I cannot comment on the technical matters but, based on the discussion, I endorse the review panel's recommendation to improve these procedures.

Model-based methods should be used with care. The review panel noted that, in a few cases, the model estimated the highest abundance in areas with no samples and it is not clear why this occurred. This could be seriously misleading if the modelled biomass estimates were used uncritically in a spatial management procedure. In addition, maps (especially colour maps!) can be very persuasive and generating maps showing high densities of scallops can easily mislead fishers, stakeholders, and decision-makers if the uncertainty in those maps is not communicated effectively. For me as a scientist, the large differences between maps generated using different modelling assumptions tells a convincing story that none of the maps can be relied upon unless there is a very good reason to choose one modelling assumption over the others. In this case, there was no such reason and there must be large model uncertainty that is very difficult to communicate to non-specialists. There are ways of capturing (some of the) model uncertainty (e.g., using Bayesian model averaging, Link & Barker 2006), but communicating uncertainty around distribution maps is much more difficult than communicating uncertainty around a one-dimensional estimate (e.g., the variance or standard error associated with an abundance estimate). Some ideas came up during the meeting, including generating maps of variance as well as maps of abundance (some were presented), and I think it would be worth continuing the development of such approaches. Cognitive testing is frequently used in social science and medical surveys to assess the ability of recipients or respondents to understand questions or information (e.g., Willis and Boeije 2013; Wilson et al. 2014), and these could be used to assess a variety of methods of communicating technical information with uncertainty to non-specialists. This is not my field, but I was involved in a technical working group that reviewed the successful application of such methods during the development of rigorously standardised computer-assisted telephone interviews for recreational fisheries in New Zealand (Wynne-Jones et al. 2014).

Conclusions and recommendations for ToR 4

The design-based methods of estimating abundance used in most of these surveys are straightforward and well-understood. Minor improvements can be made, especially to variance estimation, but none of the indices is likely to be unreliable. The model-based methods currently used for HabCam surveys still need some development. I have the following recommendations for this ToR:

- Subject to resources and other objectives, maintain broad coverage in stratified random dredge surveys to generate the time series of abundance indices for the stock assessment model (see also ToR1)
- Re-examine the current assumed dredge efficiency scalars of 40% and 24% for sand and gravel, respectively
- Assess and correct for edge and detectability errors in SMAST surveys (see also ToR2)
- Assess bias in estimates of precision from systematic surveys using various estimators and consider the application of geostatistical approaches
- Continue the development of geostatistical modelling approaches for abundance and biomass estimation (alongside developments in survey design)
- Explore methods of communicating complex and uncertain results to non-specialists, possibly including cognitive testing of different approaches with the target audience(s)

4.5. ToR 5: Integrating and using surveys for management

The ToR was to evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

The panel concluded all presentations addressed this term of reference satisfactorily and, although there was some confusion about what was meant by this ToR, I agree with that conclusion.

The NEFSC and VIMS dredge surveys have been analysed together successfully and this is appropriate because the same dredge gear is used in both surveys and there is good evidence that there is no vessel effect. The two surveys are not generally conducted at precisely the same time, however, and there could be modest changes in the populations being surveyed because growth and mortality processes are going on between the first survey and the second. For a relatively long-lived scallop species like this one, this should not be a major issue, but most scallops exhibit temporally and spatially variable growth and mortality so the effect should always be borne in mind when combining data.

An alternative approach to pooling the samples is to integrate or combine survey biomass estimates by method. The different timing of surveys is an issue here too, and coverage of different components of the stock by different survey methods brings obvious challenges. The panel was told of two methods of combining estimates from the various surveys using straight average and inverse variance weighting. Straight averaging of surveys is simple and easily-understood, but does not account for the different precision of the estimates. Inverse variance weighting takes account of the different precisions, but is reliable only if there are reliable estimates of this precision. The surveys with uniform systematic designs (SMAST drop camera and VIMS dredge) have been analysed using methods assuming random independent stations and this almost certainly underestimates the precision of the resultant biomass estimates. Estimates of variance for HabCam surveys analysed using model-based methods rather than design-based methods should include model uncertainty. This is not always straightforward but I have seen model averaging methods applied to multiple competing model-based estimates of marine mammal abundance from mark-recapture analysis of line transect data where the size and nature of correlation between observers is unknown. This work has not yet been published but I expect it will be shortly.

The ToR has an explicit focus on methods of integration outside a stock assessment model. However, it is common practice to offer multiple indices of abundance to a stock assessment model (typically one or more fishery independent and one or more CPUE indices), and it may be worthwhile exploring the different abundance indices within the scallop stock assessment model. Some may be more consistent with other data sets included in the model and internal estimates of process error for each data set may be useful for assessing this.

One presentation to the panel introduced an analysis attempting to combine observations from all surveys in a single model using a co-kriging model. This is work in progress, but other members of the review panel noted that, strictly speaking, co-kriging attempts to improve the estimation by using covariates. In this case, different surveys are used as covariates. This is not at all my field and I do not feel qualified to comment.

Demonstrations were provided to illustrate that the data could be used for other management purposes (e.g. early detection of recruitment, assessment of unusual mortality events, avoiding bycatch). The review panel concluded that complementary survey methods provide enhanced capabilities to achieve such objectives, particularly, since no survey method has provided complete coverage of the entire stock area on a regular basis. I completely agree with that conclusion.

Conclusions and recommendations for ToR 5

Current methods of combining survey data or estimates all have problems of one sort or another and further development seems required. I have the following recommendations for this ToR:

- Continue to explore methods of integrating survey indices of abundance and other data whether inside or outside of the stock assessment model
- Continue the development of "real time" methods for avoiding bycatch that could lead to catch limitation (through quota limits) or adverse effects on protected or rare species

4.6. ToR 6: Assessment of other species and ecosystem studies

The ToR was to comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

The panel concluded all presentations addressed this term of reference satisfactorily and, although I have several recommendations, I agree with that conclusion.

All survey approaches reviewed have the potential to contribute to assessments for non-scallop species and some time series are already used routinely in stock assessments for other species (e.g., for yellowtail flounder, Legault et al. 2014). There may be other species for which sufficient data can be generated by either dredges or optical surveys, but coverage of a reasonable fraction of the other stock's distribution would be required. Clearly, the scallop surveys are targeted at locations and depths where scallops are more common and there would be limitations to indices generated for species that range outside of these bounds. I don't know enough about the distribution and importance of other species that are taken in the bycatch of dredges or observed in seabed images to make an informed judgement on whether additional indices would be useful.

All survey approaches reviewed can also generate data for characterizing and mapping habitat for sea scallops and other species, understanding sea scallop ecology, and for various other types of ecosystem studies and monitoring. I agree with the rest of the panel that information from all the surveys reviewed is complementary. However, I believe the HabCam4 survey system (i.e., including the cameras, side-scan sonar, other sensors, sophisticated image processing, stereo correction, automated counting, and analytical tools) clearly has the greatest potential to provide useful information on bottom habitat, species interactions, and spatial structure on a continuously-variable range of spatial scales (especially if potential avoidance can be assessed and, if necessary, corrected for). I strongly encourage continued development of this technology and expanded coverage of surveys using HabCam4 because I believe they have the potential to provide entirely new insights, not just large amounts of data. Although the SMAST drop camera surveys have clearly provided new perspectives and opportunities for studying sea scallop and other populations, especially in closed areas, the technology is not nearly as advanced as the HabCam4 system and the overall approach brings few of the advantages that HabCam4 provides.

Both dredge surveys have recorded detailed information on fewer species than has been possible in the optical surveys and both generate broad-scale abundance estimates subject to efficiency and selectivity filters and integrated over hundreds of metres. Both of these attributes limit their contribution to detailed ecosystem studies compared with optical surveys, but their broad coverage brings other advantages. The long time series and broad scale coverage of the NEFSC dredge survey are likely to be particularly useful when longer-term ecosystem studies are contemplated, especially if these include changes to community composition and/or distribution over time.

Conclusions and recommendations for ToR 6

All survey systems can provide useful information for other purposes and some such time series are already in routine use. The HabCam4 system is particularly promising in this regard, especially if the potential avoidance issues for mobile species can be addressed. I have the following recommendations for this ToR:

- Explore the potential for additional valuable time series for stock assessment and other monitoring uses to be extracted from dredge and optical samples
- Continue the development of the HabCam4 system as a tool for ecological and ecosystem studies as well as for assessing sea scallops

4.7. ToR 7: Optimal frequency and combination of methods

The ToR was to Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

The panel concluded this term of reference was addressed satisfactorily. I agree with that conclusion but it is not possible to determine optimal approaches until a full suite of clear objectives for the work has been specified. In one sense, the overall objectives are implicit in the Terms of Reference for this review, but I have not seen a single document that describes those objectives fully and in a way that could inform the development of a more structured research plan. There seems to be a general agreement that a solid time series of biomass indices across most or all of the stock is required for a stock assessment model, and this model also requires information on size composition and, particularly important for a length-based model, growth rates. A complex and somewhat adaptive spatial management regime is also in place and requires detailed and finer-scale information on the density and size composition of scallops in locations that vary from year to year. Clearly, these broad objectives will compete with one another for survey resources even in the absence of objectives on early warning of recruitment patterns, and information for other species, habitat mapping, or ecosystem studies. This makes the development of an optimal approach much more challenging and complicated than can be completed within a review meeting, and will almost certainly involve an iterative process of simulation modelling and refinement and re-casting of objectives (including performance measures for each; not a trivial task for objectives that require information on distribution). Thus, I agree with the rest of the review panel that all available information be used to devise an optimal and integrated statistical survey design (involving the use of complementary survey methods) and estimation procedure for stock size, spatial distribution, and other primary objectives.

Noting that simulations are required to gain a full appreciation of all the trade-offs and relative costs, my initial view is that the most informative package of surveys will include:

- A well-integrated and rigorously-standardised annual dredge survey potentially delivered by more than one agency) covering as much of sea scallop stock as possible as the primary monitoring tool
- Complementary sampling using HabCam4 or similarly-specified optical system with reasonable transect density in:
    - the key areas of the sea scallop stock (transects designed to increase the precision of the primary dredge surveys) and,
    - closed areas and areas potentially supporting heavy recruitment
- Bespoke studies using the most appropriate (or, if there are limitation of availability or cost, expedient) sampling approaches to examine the new questions or particular issues as these arise

I agree with the rest of the review panel that surveys should be integrated to provide a standard monitoring survey of the entire stock distribution, and that the continuity of time-series should be maintained to the fullest extent possible. Establishing this monitoring capability will compete for resources with other objectives to develop new information and understanding that cannot be derived from time-series monitoring. I believe the only realistic way of assessing these trade-offs is through simulation.

Conclusions and recommendations for ToR 7

It is not possible to estimate or specify the optimal frequency or combination of survey and sampling methods until the full suite of objectives is known. However, once the objectives are known and understood, it is possible to assess fruitful and cost-effective ways forward using simulation modelling. I have the following recommendations for this ToR:

- Specify and "weight" or rank the objectives for all surveys of the sea scallop resource
- Conduct a simulation study to assess the performance of different combinations and intensities of surveys

4.8. ToR 8: Future research and areas of collaboration

The ToR was to identify future research and areas of collaboration among investigators and institutions.

I agree with the rest of the panel that this term of reference was addressed satisfactorily.

I believe the biggest advance overall would be for users of the information generated by these various surveys to agree on a full suite of objectives, weight these relative to one another, and work with the research teams to develop performance measures for each. This would form the basis for a formal analysis (probably by simulation) to design a programme that meets those objectives (see also ToR7). This will require a fair bit of analysis of all the existing information as well as the specification of objectives, and this is far from trivial. It will take significant time and resources. However, I believe it would be the most transparent and defensible means of designing a future research programme that includes monitoring and other information needs, and the cost would be justified give the value of the fishery and the money currently spent on research.

The panel pointed out that further understanding the correlation between dredge tow catches and HabCam observations, and using model-assisted regression estimators (dredge catch versus HabCam catch) may be a simple and intuitive approach to combine and improve estimation of stock size while maintaining the continuity of the NEFSC dredge time series. If high correlation between HabCam scallop counts (for sampling units of similar lengths) is confirmed, then the HabCam counts from the total cruise track may be used as covariates to improve the abundance and biomass estimates based on the dredge counts.

I agree with the rest of the review panel that there is no compelling advantage of using both dredge and HabCam sampling gears on the same vessel during a survey. It occurred to me that, if a research dredge could be deployed on one side of a vessel and a HabCam frame on the other, then it may be possible to have rigorously paired samples using the two gears at very little cost in ship time. I do not know enough about the logistic constraints of the available vessels or HabCam to know whether this is feasible. The designer of the HabCam systems stated more than once at the meeting that the best application of this technology was through continuous sampling, thereby avoiding the downtime and risks associated with deploying and retrieving the system and generating the continuous transects that make this technology so appealing. I agree with this and with the panel that the best way to achieve high coverage of the stock and the best intensity of complementary sampling would be to run an integrated survey using two vessels, one towing HabCam more or less continuously on transects and the other deploying dredges in a stratified random design.

It was mentioned during the review that incidental mortality of discarded scallops would be examined (and those encountered but not retained by dredges?) and there appear to be three projects funded by the RSA programme in this area. Depending on the way this information is included in a stock assessment model, incidental effects can make a substantial difference to the inferences drawn, especially if fishing mortality is relatively high (e.g., McLoughlin et al. 1991 for Australian scallops; Cryer & Morrison 1997 and Cryer et al. 2009 for New Zealand scallops, both based on the use of toothed “mud dredges”) and I support this research. There seems to be enough money in the RSA-funded projects to make a good job of this work, even given the great depth and offshore location of the fisheries compared with New Zealand scallop fisheries.

Conclusions and recommendations for ToR 8

Several clear ways to improve information and understanding came up during the review and many are discussed in this and the panel's report. However, I believe the biggest advance will be gained by specifying and ranking the full suite of objectives for the information. Once this is done, it becomes much easier to design a research programme and chart a way forward. I do not have any more specific proposals for this ToR.

4.9. Overall conclusions and recommendations

4.9.1. Comments on the NMFS review process

I have no strong concerns with the review process.

The panel was provided with a great wealth of background information in good time for the review and all the presenters gave very detailed and informative presentations on their respective aspects of the work and were open and helpful in responding to questions. It was clear that there are some tensions between some parties but this is not at all unusual in fisheries and differences were dealt with professionally in the review. The meeting was well-located and well-organised, and the rapporteurs took useful notes to jog our memories after the meeting. I would like very much to thank all of the organisers and participants for assisting the review to run smoothly.

I would have liked to see more detail on the length-based stock assessment model and the projection model because this would have allowed me slightly more insight into the way some of the information is used. I think I have a reasonable understanding of this, based on my background and material I was able to chase up for myself, but half an hour at the meeting to hear about these key formal quantitative uses of the data would have been helpful, I think. I recognise that there are many less formal or qualitative uses of the data but the stock assessment and projection models are fundamental to most aspects of the current management regime and I believe they would have warranted specific discussion in an already crowded timetable for the review.

4.9.2. Overall conclusions and recommendations for sea scallop surveys

The reports, papers, and presentations prepared by the various research teams amply demonstrate the knowledge, skill, and creativity of those teams and it is in no small way that the recent success of this fishery has depended on their combined efforts. The panel found no serious flaws in the work presented and I was greatly impressed with much of what has been done. Over the years, however, it appears to me that multiple systems and some divergences of thought have led to a rather *ad hoc* collection of surveys and experiments and no obvious way to combine all the results. If money was more limiting than it appears to be in this very productive fishery, this would never have been allowed to happen and hard choices would have already been made about which surveys to continue and which to drop or curtail. I believe there is a way forward but it will require all users of the information to establish a process for specifying their respective objectives and making the judgement calls about the relative weight of each. This can form the basis for comprehensive analysis and modelling of the available data to find a combination of survey types, coverages, and frequencies that will meet the information needs in a cost-effective way. My initial view on the most powerful combination is that dredge surveys with relatively comprehensive coverage of the stock should form the kernel of a monitoring programme, and the most useful auxiliary sampling, and a great variety of other information, will probably come from expanded HabCam4 (or similarly sophisticated) optical surveys. I think simulation modelling to test this should be a high priority.

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TOR 2: HabCam Group, NEFSC. Measurement error, detection and confounding factors. 36p.

TOR 3: Biological sampling aspects of the surveys. 13p.

TOR 4: Methods for using survey data to estimate abundance indices. 20p.

TOR 5: Co-kriging as a method for combining resource surveys, decreasing uncertainty, and mitigating bias. 13p.

TOR 6: Potential of HabCam surveys for non-scallop species, habitat, sea scallop ecology, and ecosystem studies. 9p.

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Appendix 2: Copy of Statement of Work

Statement of Work (version dated 13 March 2015, some formatting changed to condense)

Review of Sea Scallop Survey Methodologies and Their Integration for Stock Assessment and Fishery Management

BACKGROUND

The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Representative (COR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are independently selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

SCOPE

Project Description: On April 20, 2012, the New England Fishery Management Council voted to task its Science and Statistical Committee (SSC) "to 1) review the sea scallop HabCam survey technology and methods to determine if the HabCam is appropriate at this time for performing annual sea scallop surveys; 2) review how HabCam results will be integrated into sea scallop assessments for determining biomass and fishing mortality, and determine the impacts of reduced survey coverage from current dredge and SMAST video surveys." Further discussions broadened the scope of this task to examine all of the primary survey methods for assessing sea scallop abundance. Methods include scallop dredge surveys conducted on research vessels, scallop dredge surveys conducted on commercial vessels, the drop camera survey implemented by SMAST, and the HabCam system developed by WHOI and NEFSC. The objectives of this broadened scope are to assess the strong and weak points of each sampling approach, and identify the complementary facets of each survey methodology and opportunities for each method as part of the scallop survey sampling program going forward.

The purpose of this meeting will be to provide an external peer review of survey methodologies currently being used which provide data for sea scallop stock assessments and related fishery management models.

OBJECTIVES

The review panel will be composed of four appointed reviewers from the Center of Independent Experts (CIE), and an independent chair from the SSC of the New England or Mid-Atlantic Fishery Management Council. The panel will write the Panel Summary Report and each CIE reviewer will write an individual independent review report.

Duties of reviewers are explained below in the "**Requirements for the Reviewers**", in the "**Charge to the Review Panel**" and in the "**Statement of Tasks**". The Terms of Reference (ToRs) are attached in **Annex 2**. The draft agenda of the panel review meeting is attached in **Annex 3**.

Requirements for the reviewers: Four reviewers shall conduct an impartial and independent peer review of **sea scallop** survey methodology, and this review should be in accordance with this SoW and ToRs herein. Collectively, the reviewers shall have advanced knowledge, recent experience and:

1. Expertise in use of optical imaging in estimating abundance in marine biological surveys
2. Expertise in statistical design and estimation of surveys for stock assessments including stratified random, systematic and transect surveys.
3. Expertise with model-based estimation of abundance using geostatistical tools.
4. Expertise in the use of dredge surveys for sessile benthic organisms.

Knowledge of sessile invertebrates and spatial management would be desirable.

PERIOD OF PERFORMANCE

The contractor shall complete the tasks and deliverables as specified in the schedule of milestones within this statement of work. Each reviewer's duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Not covered by the CIE, the Chair's duties should not exceed a maximum of 10 days (i.e., several days prior to the meeting for document review; the peer review meeting; several days following the meeting for Panel Summary Report preparation).

PLACE OF PERFORMANCE AND TRAVEL

Each reviewer shall conduct an independent peer review during the panel review meeting scheduled in New Bedford, Massachusetts during March 17-19, 2015.

STATEMENT OF TASKS

Charge to the Review Panel:

The panel will review field and analytical procedures used by each survey in estimating sea scallop abundance and biomass and collecting biological data that contribute to resource assessment and management of sea scallops and other species. Describe the strengths, weaknesses and the opportunities for improvement in the surveys, including their methods and estimators, as an overall program that serves as a basis for abundance and biomass estimates used in annual area-based scallop fishery management procedures and triennial benchmark stock assessments. Finally, describe opportunities for using each survey in monitoring and managing resources other than sea scallops.

Each reviewer shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Tasks prior to the meeting: The contractor shall independently select qualified reviewers, without conflicts of interest, to conduct an independent scientific peer review of reports and presentations prepared by NEFSC and other groups in accordance with the tasks and ToRs within the SoW. Upon completion of the independent reviewer selection by the contractor's technical team, the contractor shall provide the reviewer information (full name, title, affiliation, country, address, email, FAX number, and CV suitable for public distribution) to the COR, who will forward this information to the NMFS Project Contact no later than the date specified in the Schedule of Milestones and Deliverables. The contractor shall be responsible for providing the SoW and ToRs to each reviewer. The NMFS Project Contact will be responsible for providing the reviewers with the background documents, reports for review, foreign national security clearance, and other information concerning pertinent meeting arrangements. The NMFS Project Contact will also be responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COR prior to the commencement of the peer review.

Foreign National Security Clearance: The reviewers shall participate during a panel review meeting possibly at a government facility, and the NMFS Project Contact is therefore responsible for obtaining the Foreign National Security Clearance approval (if the meeting is held on federal property) for the reviewers who are non-US citizens. For this reason, the reviewers shall provide by FAX (or by email if necessary) the requested information (e.g., 1.name [first, middle, and last], 2.contact information, 3.gender, 4.country of birth, 5.country of citizenship, 6.country of permanent residence, 7.whether there is dual citizenship, 8.country of current residence, 9.birth date [mo, day, year], 10.passport number, 11.country of passport) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/.

Pre-review Background Documents and Working Papers: Approximately two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the Chair and CIE reviewers the necessary background information and reports (i.e., working papers) for the peer review. Should documents need to be mailed, the NMFS Project Contact will consult with the COR on where to send documents. The reviewers are responsible only for the pre-review documents that are delivered to the contractor in accordance to the SoW scheduled deadlines specified herein. The reviewers shall read all documents deemed as necessary in preparation for the peer review.

Tasks during the panel review meeting: Each reviewer shall conduct the independent peer review of documents and presentations in accordance with the SoW ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs shall not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COR and contractor.** Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified herein. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact is responsible for ensuring that the Chair understands the contractual role of the CIE reviewers as specified herein. The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Chair: Act as chairperson, where duties include control of the meeting, coordination of presentations and discussions, ensuring all Terms of Reference are reviewed, controlling document flow, and facilitating discussion. During the question and answer periods, provide appropriate feedback to the scientists on the sufficiency of their analyses and presentations. It is permissible to request additional information if it is needed to clarify or correct an existing analysis and if the information can be produced in the time allotted.

CIE reviewers: Participate as peer reviewer in panel discussions on validity, results, recommendations, and conclusions. From a reviewer's point of view, determine whether each Term of Reference was completed successfully. During the question and answer periods, provide appropriate feedback to the scientists on the sufficiency of their survey methods and related analyses. It is permissible to request additional information if it is needed to clarify or correct an existing analysis and if the information can be produced in the time allotted.

Tasks after the panel review meeting:
CIE reviewers: Each CIE reviewer shall prepare an Independent CIE Report (see Annex 1). This report should comment, for each TOR as appropriate, on the strengths and weaknesses of the surveys, both individually and as a group going forward. The report should follow the guidance provided in the "Charge to the Review Panel" statement. During the meeting, additional questions that were not in the Terms of Reference but that are directly related to the assessments may be raised. Comments on these questions should be included in a separate section at the end of the Independent CIE Report produced by each reviewer. The Independent CIE Report can also be used to provide greater detail than the Panel Summary Report.

Chair: The Chair shall prepare a document summarizing the background of the work to be conducted as part of the review process and summarizing whether the process was adequate to complete review of the Terms of Reference. If appropriate, the chair will include suggestions on how to improve the process. This document will constitute the introduction to the Panel Summary Report (see **Annex 4**).

Chair and CIE reviewers: The Chair, with the assistance from the CIE reviewers, will prepare the Panel Summary Report. Each CIE reviewer and the chair will discuss whether they hold similar views on each ToR and whether their opinions can be summarized into a single conclusion for all or only for some of the ToRs. For ToRs where a similar view can be reached, the Panel Summary Report will contain a summary of such opinions. In cases where multiple and/or differing views exist on a given ToR, the Panel Summary Report will note that there is no agreement and will specify - in a summary manner – what the different opinions are and the reason(s) for the difference in opinions. The chair's objective during this Panel Summary Report development process will be to identify or facilitate the finding of an agreement rather than forcing the panel to reach an agreement. The chair will take the lead in editing and completing this report. The chair may express the chair's opinion on each Term of Reference, either as part of the group opinion, or as a separate minority opinion. The Panel Summary Report (please see **Annex 4** for information on contents) should address each of the ToRs, keeping in mind criteria in the "Charge to the Review Panel". The contents of the draft Panel Summary Report will be approved by the CIE reviewers by the end of the Panel Summary Report development process. The chair will complete all final editorial and formatting changes prior to approval of the contents of the draft Summary Report by the CIE reviewers. The Chair will then submit the approved Summary Report to the NEFSC contact.

DELIVERY

Each reviewer shall complete an independent peer review report in accordance with the SoW including required format and content as described in **Annex 1**. Each reviewer shall complete the independent peer review addressing each ToR listed in **Annex 2**.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate during the panel review meeting in New Bedford, MA, scheduled during March 17-19, 2015.
3) Conduct an independent peer review in accordance with this SoW and the ToRs (listed in **Annex 2**).
4) No later than April 3, 2015, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Dr. Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and to Dr. David Sampson, CIE Regional Coordinator, via email to david.sampson@oregonstate.edu. Each CIE report shall be written using the format and content requirements specified in **Annex 1**, and address each assessment ToR in **Annex 2**.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

February 6, 2015	Contractor sends reviewer contact information to the COR, who then sends this to the NMFS Project Contact
March 2, 2015	NMFS Project Contact will attempt to provide reviewers the pre-review documents
March 17-19, 2015	Each reviewer participates and conducts an independent peer review during the panel review meeting in New Bedford, MA. Chair and CIE reviewers work at drafting reports during meeting
April 3, 2015	Reviewers submit draft independent peer review reports to the contractor's technical team for independent review
April 3, 2015	Draft of Panel Summary Report*, reviewed by all CIE reviewers, due to the Chair
April 10, 2015	Chair sends Final Panel Summary Report, approved by CIE reviewers, to NEFSC contact
April 17, 2015	Contractor submits individual peer review reports to the COR who reviews for compliance with the contract requirements
April 22, 2015	The COR distributes the final individual reports to the NMFS Project Contact and regional Center Director

* The Summary Report will not be submitted, reviewed, or approved by the CIE.

The NEFSC Project Contact will assist the chair prior to, during, and after the meeting in ensuring that documents are distributed in a timely fashion.

NEFSC staff and the Chair will make the final Panel Summary Report available to the public.

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The

Contracting Officer will notify the COR within 10 working days after receipt of all required information of the decision on substitutions. The COR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: The deliverables shall be the final peer review report from each reviewer that satisfies the requirements and terms of reference of this SoW. The contract shall be successfully completed upon the acceptance of the contract deliverables by the COR based on three performance standards:
(1) each report shall be completed with the format and content in accordance with **Annex 1**,
(2) each report shall address each ToR listed in **Annex 2**,
(3) each report shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Upon the acceptance of each independent peer review report by the COR, the reports will be distributed to the NMFS Project Contact and pertinent NMFS science director, at which time the reports will be made publicly available through the government's website. The contractor shall send the final reports in PDF format to the COR, designated to be William Michaels, via email William.Michaels@noaa.gov

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Annex 1: Format and Contents of Independent Individual Peer Review Report

1. The independent peer review report shall be prefaced with an Executive Summary providing a concise summary of the strengths and weaknesses of the reviewed sea scallop surveys, both individually and when used in combination.

2. The main body of the report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Key findings on work reviewed, and an explanation of their conclusions and recommendations (strengths, weaknesses of the analyses, etc.) for each ToR.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including a concise summary of strengths and weaknesses of the analyses and recommendations for the future.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Panel Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The individual independent report shall be a stand-alone document for others to understand the proceedings and findings of the meeting, regardless of whether or not others read the Panel Summary Report. The independent report shall be an independent peer review of each ToR, and shall not simply repeat the contents of the Panel Summary Report.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of this Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference

(These ToRs are to be carried out by the scientists involved with scallop survey methods and analyses. The Peer Review Panel will then address the strengths and weaknesses of the various survey approaches and survey methodologies, with a focus on these ToRs.)

1. Review the statistical design and data collection procedures for each survey system
   a. Dredge surveys conducted on research vessels
   b. Dredge surveys conducted on commercial vessels
   c. SMAST video drop camera system
   d. HabCam camera and sensor sled

2. For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (*e.g.,* light, turbidity, sea state, tide etc.)

3. Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (*e.g.,* Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

4. Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

5. Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

6. Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

7. Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

8. Identify future research and areas of collaboration among investigators and institutions.

Appendix to Annex 2:

In their presentations and reports for the peer review, analysts (as opposed to the peer reviewers) will cover a broad range of topics, such as:

1. Summaries of historical scallop survey indices, and their components (e.g., frequency, spatial extent, data collected), from the NEFSC sea scallop survey, the SMAST video survey, relevant VIMS cooperative industry surveys, and HabCam surveys from WHOI and Arnie's Fisheries. For each of these surveys, additional topics include survey design, objectives, methods, and any relevant changes over time.
2. Summaries of current approaches for using abundance indices in stock assessment and management models. (Stock assessment models describe the dynamics of populations over time and estimate total stock size and mortality rates. Management models are used to evaluate the short-term effects of alternative harvesting scenarios at varying degrees of spatial resolution.)
3. Summaries of procedures for data acquisition, post processing, archiving, availability to outside investigators, publication of derived products in primary literature, and use for stock assessments.

Rules of Engagement among analysts on Working Groups preparing for peer reviews:

Anyone participating in working group meetings that will be running or presenting results from a design or model based estimator is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed description in advance of the meeting. These measures allow transparency and a fair evaluation of differences that emerge among design and model based estimates of abundance.

Annex 3: Draft Agenda
Sea scallops Survey methods review

March 17-19, 2015

(Location: New Bedford, Mass.)

DRAFT AGENDA* (version: October 17, 2014)

TOPIC		PRESENTER(S)	RAPPORTEUR
Tuesday, March 17			
9 – 9:30 AM	Welcome Introduction Agenda Conduct of Meeting	**Chair**	**TBD**
9:30 – 10:30 AM	Presentation #1	**TBD**	**TBD**
12:30 – 1:30 PM	Lunch		
1:30 – 3:30 PM	Presentation #2	**TBD**	**TBD**
3:30 – 3:45 PM	Break		
3:45 – 5:45 PM	Presentation #3	Chair	**TBD**
5:45 – 6 PM	Public Comments		

TOPIC		PRESENTER(S)	RAPPORTEUR
Wednesday, March 18			
9 – 10:45 AM	Presentation #4	**TBD**	**TBD**
10:45 – 11 AM	Break		
11 – 12:30 PM	Presentation #5	**TBD**	**TBD**
12:30 – 1:45 PM	Lunch		
1:45 – 3:15 PM	Presentation #6	TBD	**TBD**
3:15 – 3:30 PM	Public Comments		
3:30 -3:45 PM	Break		
3:45 – 6 PM	Presentation #7	**TBD**	TBD
7 PM	**(**Social Gathering **)**		
Thursday, March 19			
8:30 – 10:15	Review of Key Findings	Chair	**TBD**
10:15 – 10:30	Break		
10:30 – 12:30	Edit Summary Report	Chair	**TBD**
12:30 – 1:45 PM	Lunch		
1:45 – 2:15 PM	Edit Summary Report	Chair	**TBD**
2:15 – 2:30 PM	Break		
2:30 – 5 PM	Edit Summary Report	Chair	**TBD**

*All times are approximate, and may be changed at the discretion of the Chair. The meeting is open to the public.

The NMFS Project contact will provide the final agenda about four weeks before meeting. Reviewers must attend the entire meeting.

Annex 4: Contents of Review Panel Summary Report

1. The main body of the report shall consist of an introduction prepared by the Chair that will include the background, a review of activities and comments on the appropriateness of the process in reaching the goals of the Review. Following the introduction, for each ToR the report should address the issues described earlier in the "Charge to the Review Panel" within the "Statement of Tasks".

2. To make its determinations, the Chair and CIE reviewers should consider whether the survey methods provide a scientifically credible basis for estimating sea scallop abundance. Scientific criteria to consider include: whether the methodologies and estimators are adequate and used properly, and are leading to conclusions that are correct/reasonable. If the CIE reviewers and chair do not reach an agreement on a Term of Reference, the report should explain why. It is permissible to express majority as well as minority opinions.

3. The report shall also include the bibliography of all materials provided during the review, and relevant papers cited in the Summary Report, along with a copy of the CIE Statement of Work.

4. The report shall also include as a separate appendix the Terms of Reference (Annex 2), including any changes to the ToRs or specific topics/issues directly requiring Panel advice.

Appendix 3: Panel membership and others attending the review.

Participants	Affiliation	Role	Contact Information
Maguire, J-J	Review Chair	Review Chair	jeanjacquesmaguire@gmail.com
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Hughes, Peter	Atlantic Cape Fisheries	Attendee	–
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